PhD Thesis Summary
論文の内容の要旨

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Study on the Quality Evaluation of Frozen Durian
冷凍ドリアンの品質評価に関する研究

Jackie Lou Japos Tagubase
ジャッキール　ハポス　タグバセ

Supervisor: Prof. Tetsuya Araki

Durian (*Durio zibethinus* Murray) is a delicacy in Southeast Asia, which upon maturity may be eaten fresh or frozen or processed into candies, jams, and purees as food flavorings, among others. On the average, the edible portion of the fruit is only 26% of its weight and the composition of the rind and seeds are 60% and 14%, respectively. It is rich in carbohydrate, calcium, phosphorous, thiamin, riboflavin, niacin, and ascorbic acid. At present, the top producing and exporting countries of this fruit are Thailand, Malaysia and Indonesia with the remainder of the region capable of small-scale production mostly to cater domestic consumption. In the Philippines, its market value and export potential is gradually becoming widely recognized due to several compelling attributes, which include: 1) lower tariff and trade liberalization under the General Agreement on Tariffs and Trade (GATT), 2) increasing global demand and 3) marked discrepancy in fruiting season relative to the aforementioned major competing countries. These relative advantages have evoked strong government initiative aimed at further enhancing the global competitiveness of Philippine durian with premium placed on product quality and safety through harnessing post-harvest technologies and researches, creating vibrant domestic and international market environment, and strengthening multi-sectorial partnership.

To date, because of durian's seasonality, the industry is processing the fruit as one of the means to absorb the excess supply during peak season and also to widen its market. Particularly, it is during this season of surplus yields that producers look to the possibility of freezing the durian pulp to preserve the excess supply and provide durian during off-seasons for durian processors and consumers. Moreover, freezing contributes to the reduction of the bulk nature of the fruit and concealing its unique but strong and aroma during shipping and distribution. Freezing is well known for keeping the quality of foods at a longer period, however, there are still quality concerns associated with it depending on the type and characteristics of the commodity. Studies have been reported for the quality changes related to the chemical and physicochemical properties, texture, color, and volatile profiles in frozen storage of some fruits. On the other hand, thawing process is also important as it may further affect the food quality after freezing. However, limited information is provided for the quality changes in the frozen and thawed durian. Moreover, the bulk of published reports in literature concerning Philippine Durian have focused on production efficiency and postharvest management anchored on the primary objective of extending the product’s storage or shelf life. Only a sparse number of evidence is available on the physicochemical and aroma qualities of few local cultivars, and these studies have unfortunately provided limited information with regard to the said characteristics. This is in stark contrast to those of Malaysian, Indonesian, and Thailand counterparts where key quality properties (physical, chemical, antioxidant, aroma) of indigenous cultivars have been extensively characterized. Therefore, a comprehensive analysis of these baseline characteristics is hereby warranted. Lastly, there is a paucity of information on the quality/characteristics of durian that is expected by potential consumers.

This study was conducted: 1) to investigate the effect of freezing and thawing particularly on the physicochemical, textural and smell properties of durian pulp; 2) to provide an exhaustive investigation of the five economically important Philippine durian cultivars (Arancillo, Duyaya, GD69, Native and Puyat) in terms of their physicochemical properties, sugars, organic acids, antioxidant and aroma components; 3) to determine the correlation between these experimental values and the consumers' perceived intensity to the quality attributes of the selected Philippine durian cultivars, and 4) to identify the most preferred cultivar among durian consumers based on their quality attributes. These objectives comprised the chapters of this paper. The findings of this study are essential in the establishment of a thawing protocol for frozen durian that will keep its good quality for durian processors and consumers. Additionally, the individual characteristics of the durian cultivars will be useful for the key players of the industry such as farmers, processors, and researchers to which cultivar/s should the development and production be focused on in order to satisfy demand for quality durian. Satisfying the consumers' demand is essential to gaining a wider market share and to a more sustainable industry.

The effect of freezing, and iced and hot water thawing on the quality of durian pulp was investigated. Mature durian pulp was removed with seeds, vacuum-packed, and frozen at -20°C. Thawing in iced water (~0°C) and hot water (~90°C) was then applied and the quality of the pulp was assessed based on physicochemical properties - pH, moisture content, soluble solids concentration (SSC), color, sugar - sucrose, glucose, and fructose and organic acid - succinic acid and citric acid content, texture and smell profile. The physico-chemical properties were analyzed using a compact pH meter (LAQUAtwin, Horiba Ltd., Kyoto) for the pH, pocket refractometer (Atago, Tokyo) for the SSC, and oven-drying method was employed for the moisture content. The surface color of the durian pulp was measured through a ZE 2000 Color Meter (Nippon Denshoku Industries Co., Ltd, Tokyo) in L*, a* and b* mode, wherein L* indicates brightness (0 = black, 100 = white), a* indicates the hue on a green to red axis (-a = green, +a = redness) and b* indicates the hue on a blue to yellow axis (-b = blue, +b = yellow). The Texture Profile Analysis was carried out using a creep meter (Rheoner II, RE 2-3305B, Yamaden Co. Ltd., Tokyo). On the other hand, High Performance Liquid Chromatography (HPLC) analysis was conducted to measure the sugars and organic acids content of the samples. Lastly, an electronic nose (e-nose) device (FF-2A Fragrance and Flavor Analyzer, Shimadzu, Kyoto) was employed to characterize the smell/odor of the samples. Mean values for the fresh and frozen thawed (iced and hot water) durian samples were statistically compared through analysis of variance (ANOVA) followed by Tukey analysis for further test of significance. While a radar chart of the smell similarity index and analogue value of the odor index plot were constructed to distinguish the similarity and strength of the smell of the fresh and frozen-thawed durian pulp. The analysis of the data was performed through the ASmell2 software, built-in to the device.

The effect of freezing and different thawing conditions on the physicochemical, textural, and aromatic attributes of durian was evident in this study. Overall, the freeze-thawing conditions have a significant impact on the moisture content, color, sugar content, and aroma profile of the durian pulp. The moisture content of the pulp increased while the brightness of the pulp color decreased significantly after hot water thawing. However, it is also necessary to consider the effect of maturity of the fruit on the observed change in the moisture content of the samples. Meanwhile, for the organic acid and sugar contents, generally, the sugar content was affected by the freezing process but not by the thawing conditions. The sugar content was significantly decreased after freezing and thawing. Furthermore, the smell profile and strength of the frozen and thawed durian pulp is generally affected by hot water thawing according to the radar plot of smell similarity index and odor index plot, respectively. No significant variations were noted in the pH, SSC, organic acids and texture of the durian pulp after freezing and thawing. It is recommended for other thawing conditions in between iced and hot water to be explored to determine the condition under which the quality variations occur. In addition, literatures reported that variety and maturity could cause variation on the effect of freezing in the fruit, thus it would be also an interesting area for further study of durian.

In the next chapter, the five economically important Philippine Durian cultivars (Arancillo, Duyaya, GD69, Native and Puyat) were comprehensively examined in terms of their color, firmness, physicochemical properties, sugars, organic acids, antioxidant and aroma components. These cultivars were preferentially selected according to consumers' preference, farmers' production and utilization in the processing industry, in addition to their excellent yield, good quality and disease resistance as certified by the National Seed Industry Council in the Philippines. Their physico-chemical properties were measured using pH meter (compact pH

meter (ph700, Eutech Instruments, Singapore) for the pH, pocket refractometer (Atago, Tokyo) for the SSC, and a bench-top moisture balance (MOC-120H, Shimadzu, Japan) for the moisture content. The surface color of the durian pulp was measured through a Chroma meter CR-410 (Konica Minolta, Inc., Japan) in L*, a* and b* mode. The firmness of the durian pulp was measured using a penetrometer (Fruit Hardness Tester KM-1; Fujiwara Scientific, Tokyo, Japan). On the other hand, HPLC analysis was conducted to measure the sugars and organic acids content of the samples. Folin–Ciocalteu assay and 2,2-diphenyl-1-picrylhydrazyl free radical (DPPH) scavenging assay were performed to measure the total phenolic content (TPC) and scavenging activity of the cultivars, respectively. An e-nose (Autosampler Odourscanner HS100, FOX4000, Alpha MOS, Toulouse, France) and Headspace-Solid Phase Microextraction (HS-SPME) Gas Chromatography - Mass Spectrometry (GCMS) were conducted to characterize the aroma/volatile components of the samples. The mean values from physicochemical and other chemical analyses (n=9) were statistically compared using One Way ANOVA with Least Significant Difference (LSD) posttest at $p<0.05$ level of significance. A radar chart and PCA plot with the mean responses of e-nose sensors in different Philippine durian cultivars samples were constructed to distinguish the similarities of the smell of the different cultivars. The analysis of the data was performed through the software, built-in to the device.

Generally, all the five cultivars varied significantly ($p<0.05$) in all the parameters tested. In terms of the color, Duyaya pulp has the brightest and strongest yellow color, while Puyat pulp has the least brightness, and Native has the palest yellow color. For the texture, Duyaya and GD69 have highest degree of pulp's firmness, and least in Native and Arancillo. In moisture content, Duyaya got the highest percentage, while Arancillo has the least. Inversely, in the TSS level, the highest value was observed in Arancillo and lowest in Duyaya. In pH, Puyat and Native have the highest value, and least in Duyaya and Arancillo. Lastly, for the % TTA, Native registered the highest TTA value, while Duyaya and Arancillo have the least percentage. The predominant sugars among the cultivars are sucrose, glucose and fructose. Sucrose is most concentrated in Arancillo and GD69, while least in Native. Meanwhile, the average concentration of glucose and fructose does not significantly vary from each other in each cultivar. The order of glucose and fructose concentration of the durian cultivars, from highest to lowest, were obtained as follows: Puyat > Native > GD69 > Duyaya and Arancillo. In their organic acid components, the predominant acids are citric, succinic and malic acid, which their average concentrations do not generally significantly differ from each other per cultivar. While tartaric acid is the least concentrated in all cultivars. For their antioxidant components, Duyaya has the highest TPC (GAE mg/100g edible portion) among the cultivars, while Puyat has the highest antioxidant capacity observed. Native has the least values in both TPC and percent antioxidant capacity. Lastly, the aroma characteristic was positively discriminated in E-nose analysis based on the radar plot of cultivars' individual sensor responses and Principal Component Analysis (PCA) plot, where in the PC1 explained 97.56% of the total variance. Their aroma as measured through headspace solid- phase microextraction (HS-SPME) coupled with gas chromatography-mass spectrometry (GCMS) analysis, is composed of about 56 to 73 volatile compounds for each cultivar, mainly esters and sulfur-containing compounds. Native has the highest number and concentration of ester compounds, while least in both the number and concentration in Arancillo. Esters are most concentrated in Native and the predominant esters in all the cultivars are ethyl 2-methylbutanoate, propyl 2-methylbutanoate and ethyl hexanoate. For the sulfur-containing compounds, 18 compounds are detected in Puyat, 11 in Duyaya, 15 in GD69, and 10 in each Native and Arancillo. GD69 has the highest total concentration of these compounds. The dominant compounds are 3,5-dimethyl-1,2,4-trithiolane, followed by diethyl disulfide. 3,5-dimethyl-1,2,4-trithiolane is most concentrated in Duyaya cultivar, while diethyl disulfide is concentration in Puyat and Native. 1-propanol and ethanol mainly comprised the carbonyl groups extracted in all cultivars. Both are majorly obtained in Puyat, Duyaya, GD69 and Native. In general, Arancillo has the least concentration of volatile compounds among the cultivars analyzed. These findings are only limited to selected durian cultivars grown in one region and it is reported that geographical difference can cause variation in the quality attributes of the product, it would be interesting to characterize and compare the same cultivars grown in different regions of the country if future studies. Furthermore, it is suggested to include also in the future analysis the imported varieties such as the Thai varieties that are already being cultivated in the Philippines.

The last chapter of the paper was conducted to determine the correlation between the experimental values and the consumers' perceived intensity of the quality attributes - color, texture, physico-chemical properties, sugars and organic acids content, and aroma of the selected Philippine durian cultivars, and to

identify the most preferred cultivar by durian consumers among the selected Philippine durian cultivars based on the quality attributes evaluated. To achieve these objectives, intensity ranking and preference-ranking tests were conducted, which were participated by 50 durian consumers, respectively. Randomly coded samples were simultaneously served to the panelists and, for the intensity ranking test, they were tasked to rank the intensity of each quality attribute per sample by writing the code number of the sample on the appropriate scale, with 1-as the weakest and 5-as the strongest intensity. On the other hand, for the preference-ranking test, the panelists were asked to evaluate and rank the samples in order of their preference, from 1- as the most preferred to 5- as the least preferred sample. They were allowed to re-evaluate the samples as necessary to make the required comparisons among them. The data were then tested for significant differences by comparing the rank totals between all possible pairs of samples using the Friedman Test with Wilcoxon Signed Rank Test as posthoc test. The findings were also matched with the experimental values of the quality attributes to evaluate their correlation/association.

The results of the intensity ranking through consumer perception descriptively showed some association with the measured values in color parameters, texture, sweetness and overall flavor. In general, the panel among the other samples easily distinguished those with higher values/ concentrations. But, the difference with those lesser values are indistinguishable from each other. For the aroma analysis, the results are quite challenging to correlate since it is also challenging to identify the compounds that contribute to the overall aroma of the samples. Moreover, the sample condition during the analysis might also have contributed to uniform intensity of the aroma of the samples. The samples were served cold to the panel to reduce oxidation that may affect the color of the samples. The low temperature may have suppressed the release of aroma during analysis. Lastly, in the preference-ranking test, some association to the intensity of the quality attributes was evident. In terms of the color, Duyaya is the most preferred, which was also perceived to have the brightest yellow color. On the other hand, Arancillo got the highest preference regarding the texture, yet it was previously noted having the least firmness among all the cultivars. This suggests that the panel prefer durian with softer texture. For the taste/flavor, the top choices are Arancillo, Duyaya, and Native, where in Arancillo also emerged as the sweetest and with strongest flavor. For aroma, Puyat, GD69 are more preferred over Native and Duyaya, with Arancillo in the average. For the overall preference, considering all the characteristics in a single evaluation, the Duyaya, Arancillo, Native cultivars are more preferred by the panel, although the differences on the preference among the cultivars is just moderate. Arancillo has consistently acquired high preference in all the attributes evaluated, which may also have influenced its high overall consumer preference among the durian cultivars. Although it should also be noted that consumer preferences may be affected by regional, cultural, gender and age factors. Thus, it is recommended for future studies the preference of consumers from other regions of the country.